

Invited talk of David Tomanek

at the 1997 APS March Meeting

(M3.03 -- Thursday morning, March 20,
at 09:12 a.m. in Room 1203A, Convention Center)

Morphology, Growth and Destruction of Carbon Nanotubes

As an important milestone in the history of carbon (C), the discovery of fullerenes has been honored by the 1996 Nobel prize to Robert F. Curl, Harold W. Kroto and Richard E. Smalley. Since the identification of the C₆₀ "buckyball" in 1985, the field of fullerenes has experienced unparalleled growth.

Maybe the most intriguing new development is the successful synthesis of a new material that consists of 100% carbon. Latest research results from Smalley's research group at Rice University [1] indicate that this material consists of identical hollow "nanotubes" that are only 1.4 nano-meters (twice the size of the "buckyball") in diameter, but up to 0.1 milli-meters long. Hundreds of such **nanotubes bundle to strong nanoropes**.

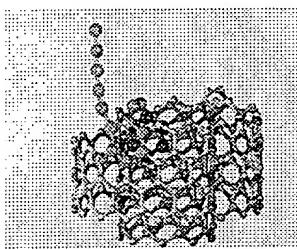
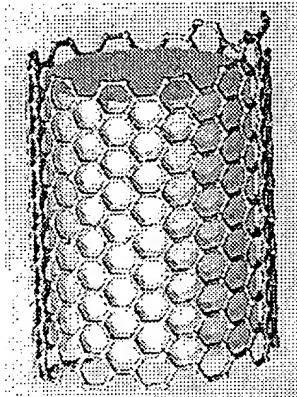
Some of the **unique properties** of nanotubes are their high tensile strength, which is near 100 times that of steel of the same dimension, at substantially lower weight. Their high stiffness towards bending exceeds that of known materials. Nanotubes are also very good electrical conductors. Individual nanotubes may be the thinnest man-made structures that are stiff enough to be self-supporting, and chemically inert in the atmosphere.

The **synthesis** of this new material by laser-evaporation of graphite enriched by a nickel-cobalt alloy is relatively uncomplicated when measured by today's technology standards. The extremely high 80-90% efficiency of nanorope production from the raw material is intriguing, as it suggests catalytically assisted self-assembly on the atomic scale. Still, significantly more research will be needed before bulk production can be expected. Significant progress in this direction is reported from Richard E. Smalley's research group at the Rice Center for Nanoscale Science and Technology.

Speculations about the **most important future application** of nanotubes are only of limited value; surely nobody suspected the discovery of the laser to affect our everyday life most in scanners at checkout counters in supermarkets. Likely applications of carbon nanotubes might be connected with their extremely good mechanical properties, such as strength and stiffness. These would suggest nanotubes to find use in new **composite materials and micro-machines**, extremely tough and non-toxic fibers/fabrics for **medical applications**, even light-weight bullet-proof vests. Light metal alloy composites containing carbon nanotubes could prove to be very interesting for the **aerospace and Stealth technology** that requires high-strength, low-weight materials that are hard to detect electronically. New Atomic Force Microscopy probes are being used to investigate nanostructures with crevasses that are narrow on the atomic scale. But there are other unique aspects: nanotubes are **quasi one-dimensional perfect nanowires** for electronic applications. These hollow and chemically inert tubes could also find use as "nano-pipelines" to transport molecules into individual cells (like miniature hypodermic needles).

Whichever will turn out to be the most significant future application of nanotubes and buckyballs, it will be the fruit of long-term financial support of fundamental research by U.S. federal funding agencies, such as the National Science

Foundation, the Office of Naval Research, and the Air Force Office of Scientific Research.



David Tomanek's invited contribution at the 1997 March Meeting of the American Physical Society will address the following nanotube related questions in the light of recent theoretical calculations and experimental data:

- Under what conditions do carbon atoms condense to hollow graphitic cylinders of amazing strength, the nanotubes, rather than forming fullerenes, graphite, or diamond?
- Why do minute quantities of Ni or Co in the graphite source material cause the formation of ordered bundles of identical single-wall nanotubes that grow up to 0.1 milli-meters long, yet only 1.4 nano-meters in diameter? [1,2]
- Which conditions lead to the preferential formation of single- and multi-wall structures (tubes, "onions")?
- Are growing multi-wall nanotubes stabilized against closure by strong covalent bonds that bridge the gap between adjacent walls at the growing edge?
- How stable are carbon nanotubes in external electric fields, and do they preferably disintegrate by "unraveling" atomically thin carbon chains (like a sleeve of a pullover)? [3]

[1] Andreas Thess, Roland Lee, Pavel Nikolaev, Hongjie Dai, Pierre Petit, Jerome Robert, Chunhui Xu, Young Hee Lee, Seong Gon Kim, Daniel T. Colbert, Gustavo Scuseria, David Tomanek, John E. Fischer, and Richard E. Smalley, Crystalline ropes of metallic carbon nanotubes, *Science* **273**, 483 (1996).

[2] Young Hee Lee, Seong Gon Kim, and David Tomanek, Catalytic growth of single-wall nanotubes: An *ab initio* study, *Physical Review Letters* **78** (1997).

[3] A.G. Rinzler, J.H. Hafner, P. Nikolaev, L. Lou, S.G. Kim, D. Tomanek, D.T. Colbert, and R.E. Smalley, Unraveling Nanotubes: Field Emission from an Atomic Wire, *Science* **269**, 1550 (1995).



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